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EOR CENTRE

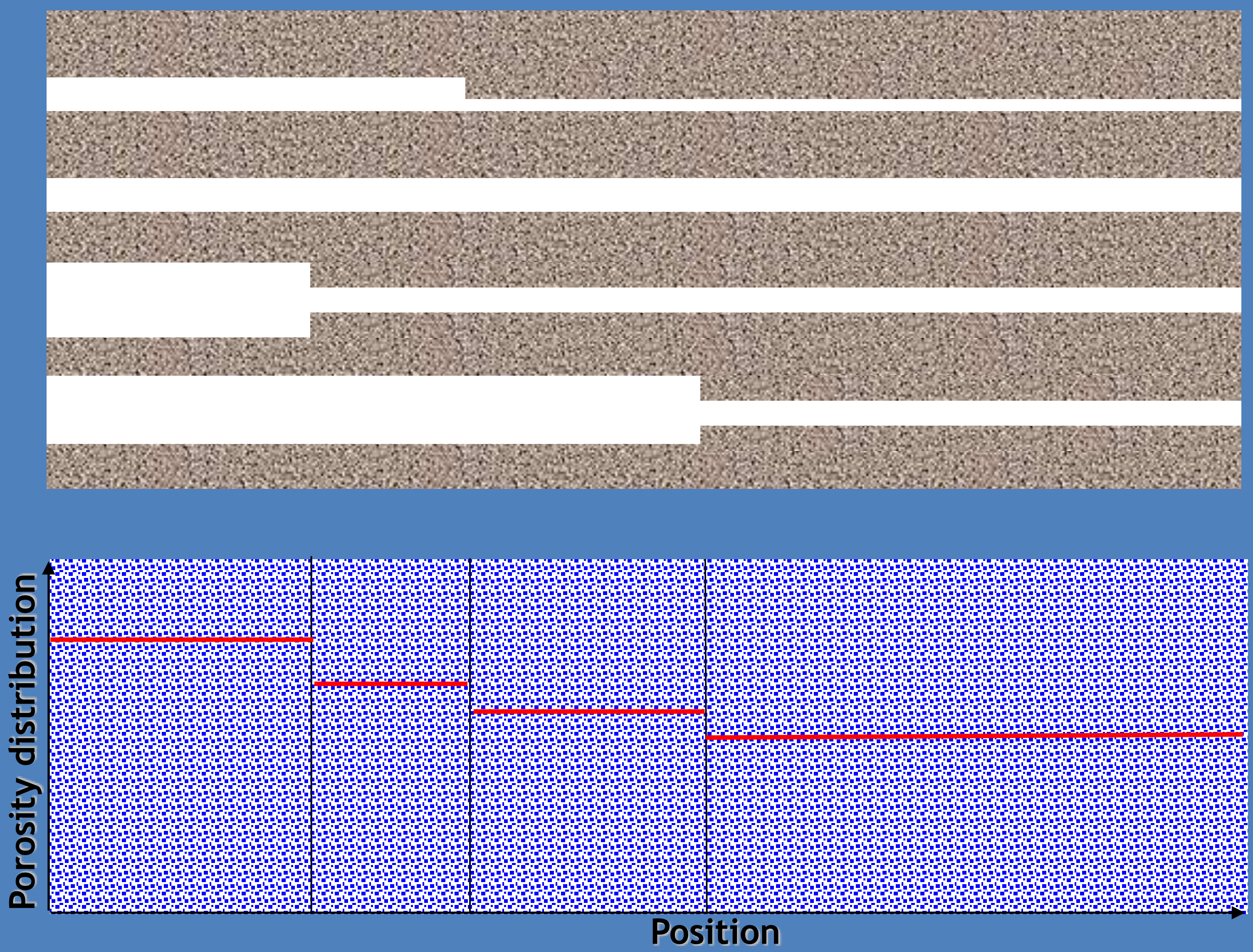
SPWLA

Measurements, analysis and interpretation of SCAL data

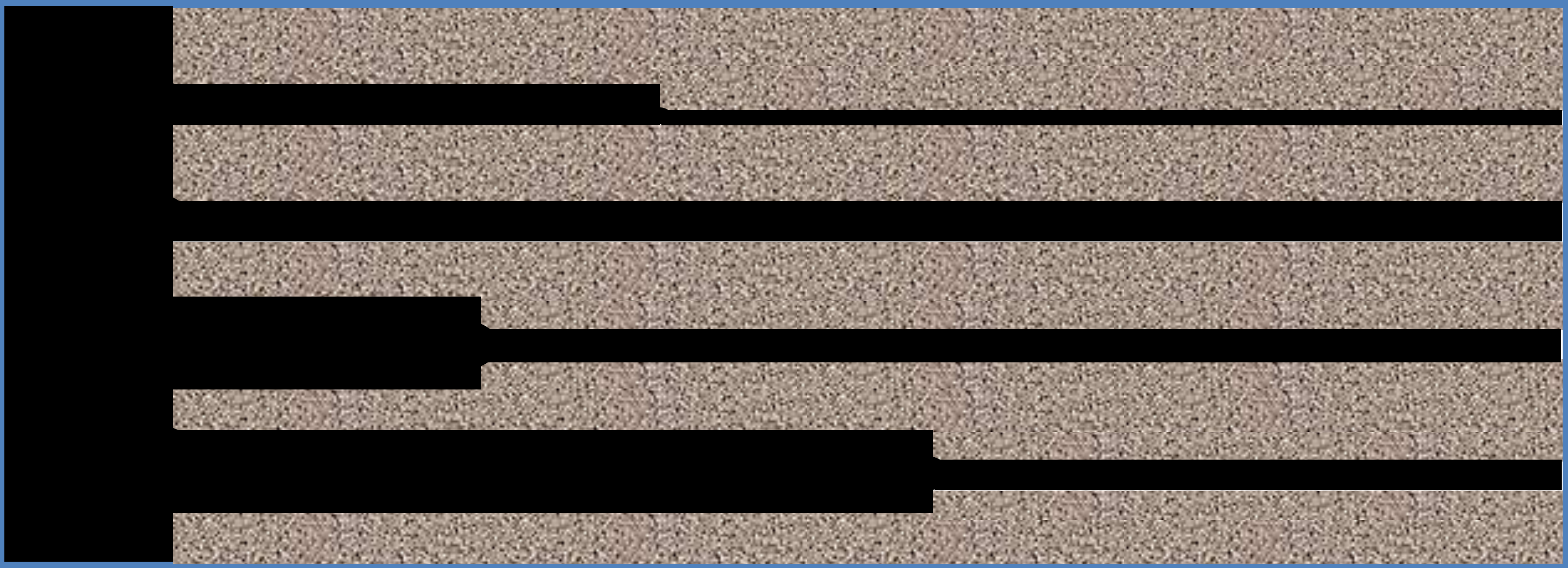
Outline

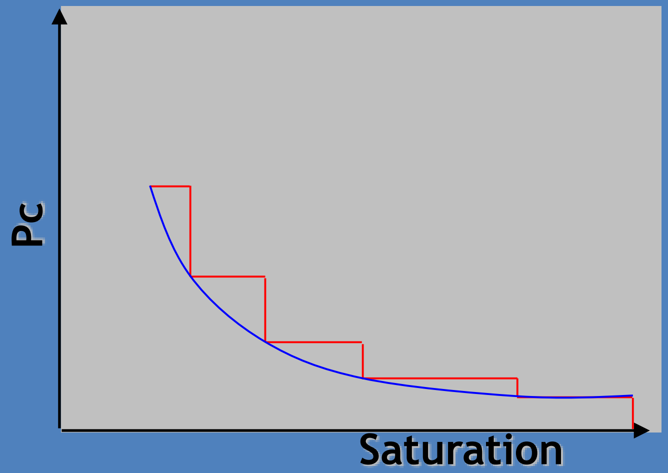
- Experimental Design
- Drainage versus imbibition
- Experimental Pc techniques (with and without resistivity)
  - Mercury Injection technique
  - Equilibrium technique
  - Continuous injection technique
  - Centrifugation
- Numerical interpretation
- Examples of misleading SCAL results
- Examples of correct/incorrect use of reliable SCAL data in models

Experimental Design

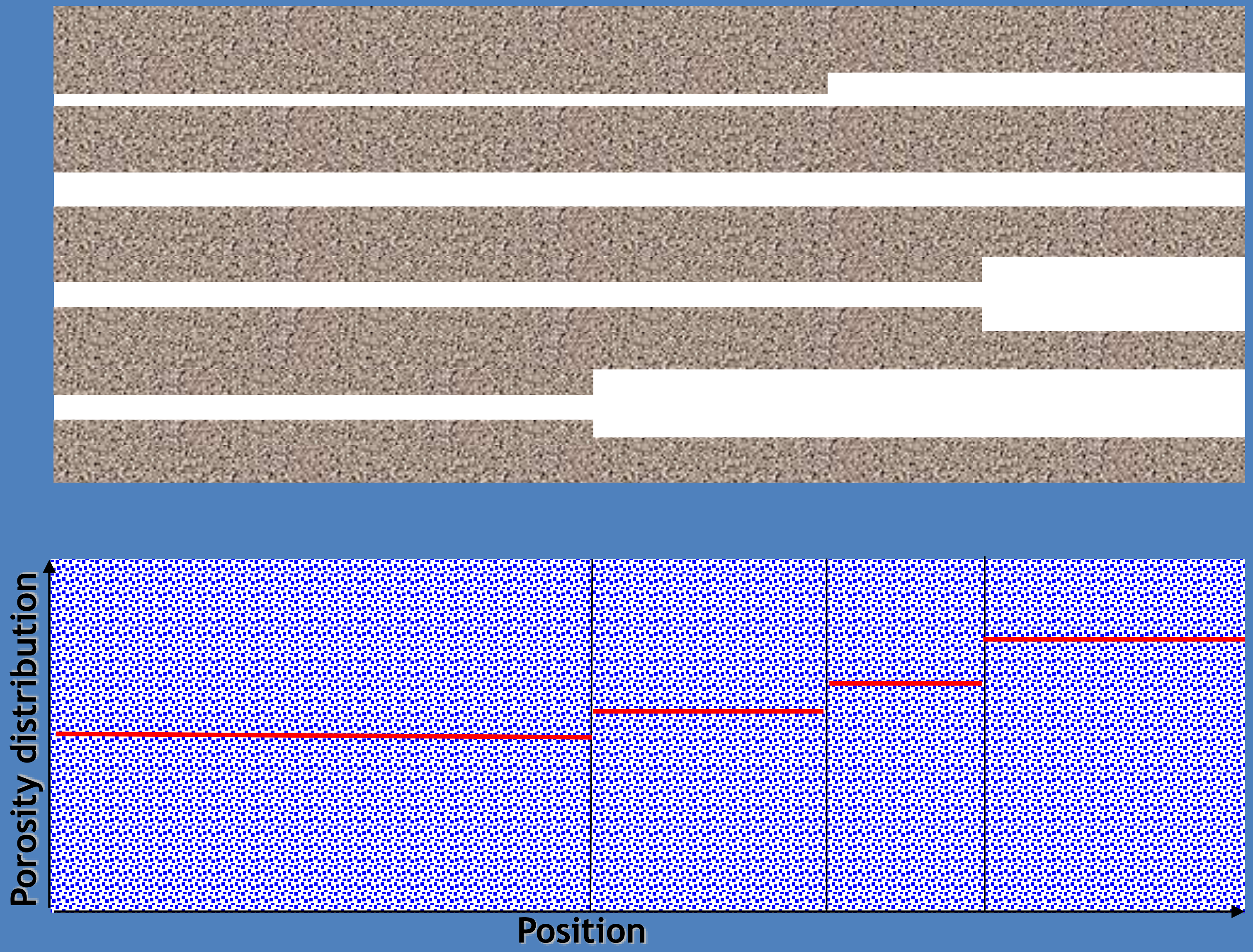


Experimental Design

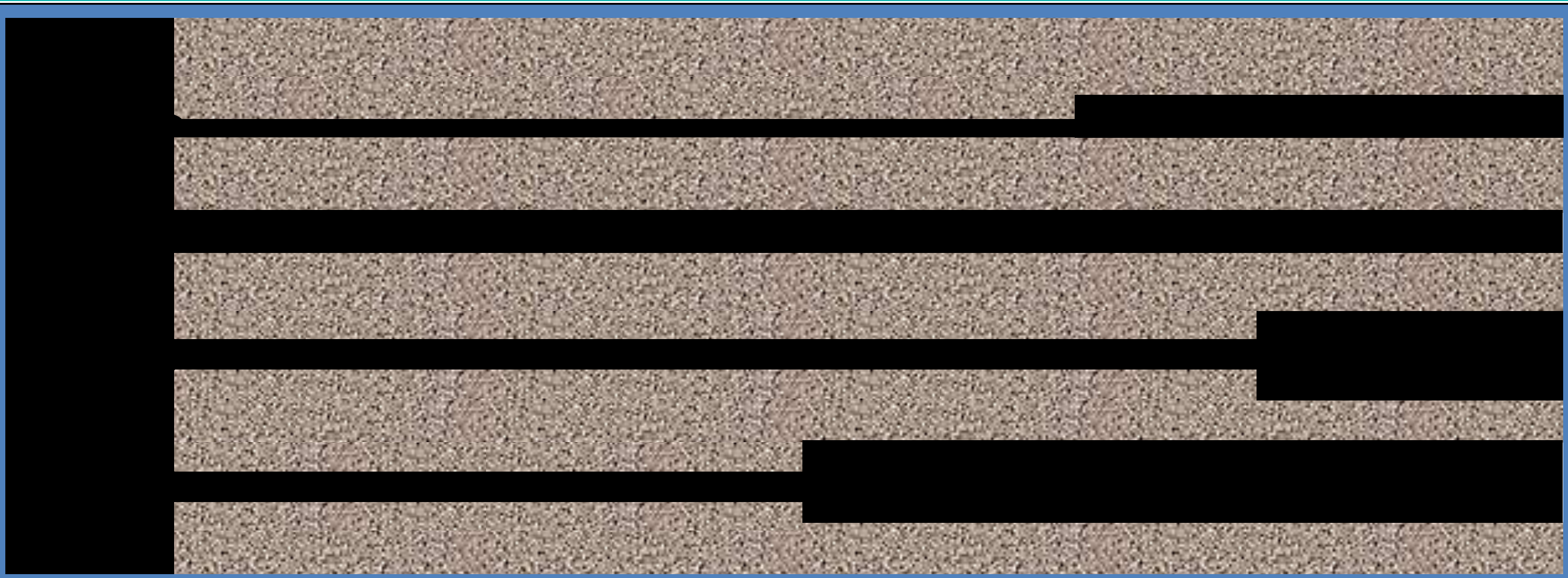




Experimental Design

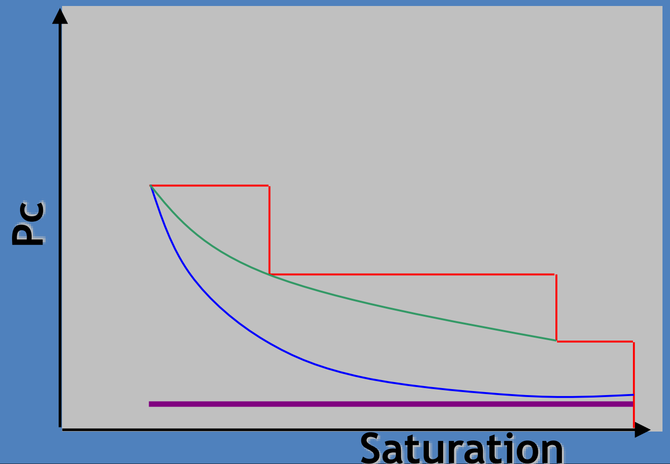


Experimental Design

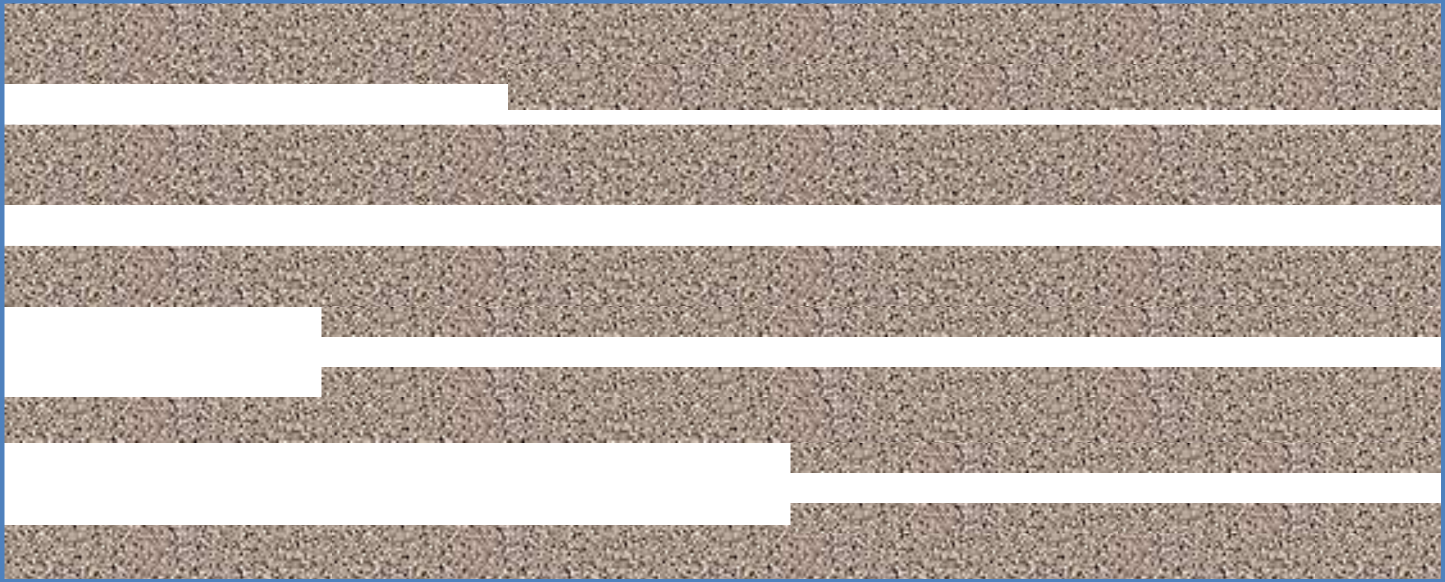


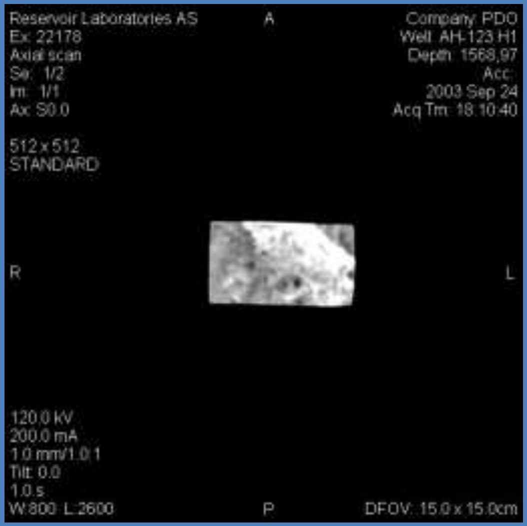
Which Pc curve is the correct one ?

If all capillaries was 100 % oil wet (prior to invasion), how does the Pc look like



Experimental Design





This core plug was used in a SCAL study !

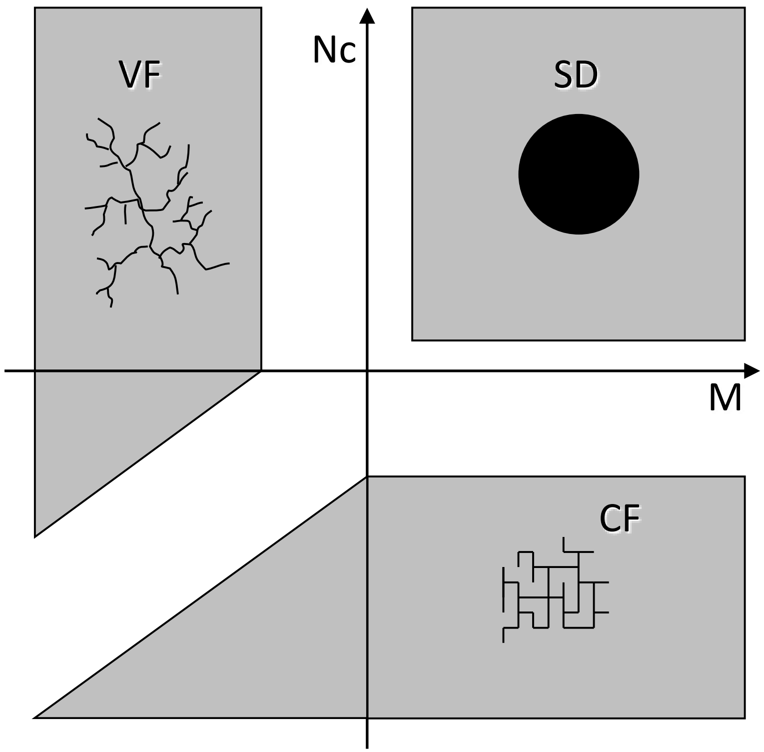
Experimental Design

Lenormand's phase-diagram for primary drainage:

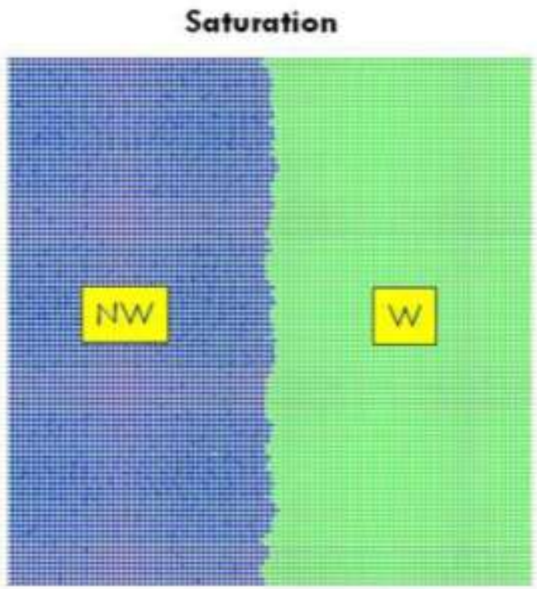
$$Nc = \frac{q \cdot \mu}{\sum \cdot \sigma} \qquad M = \frac{\mu_{invading}}{\mu_{defending}}$$

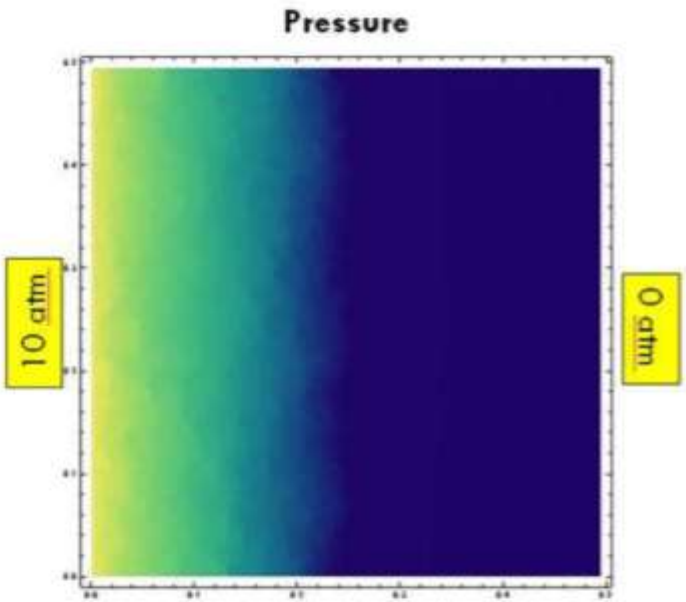
Where:

- q Injection rate
- σ Interfacial tension
- $\sum$ Cross section of inflow
- μ Viscosity



Experimental Design

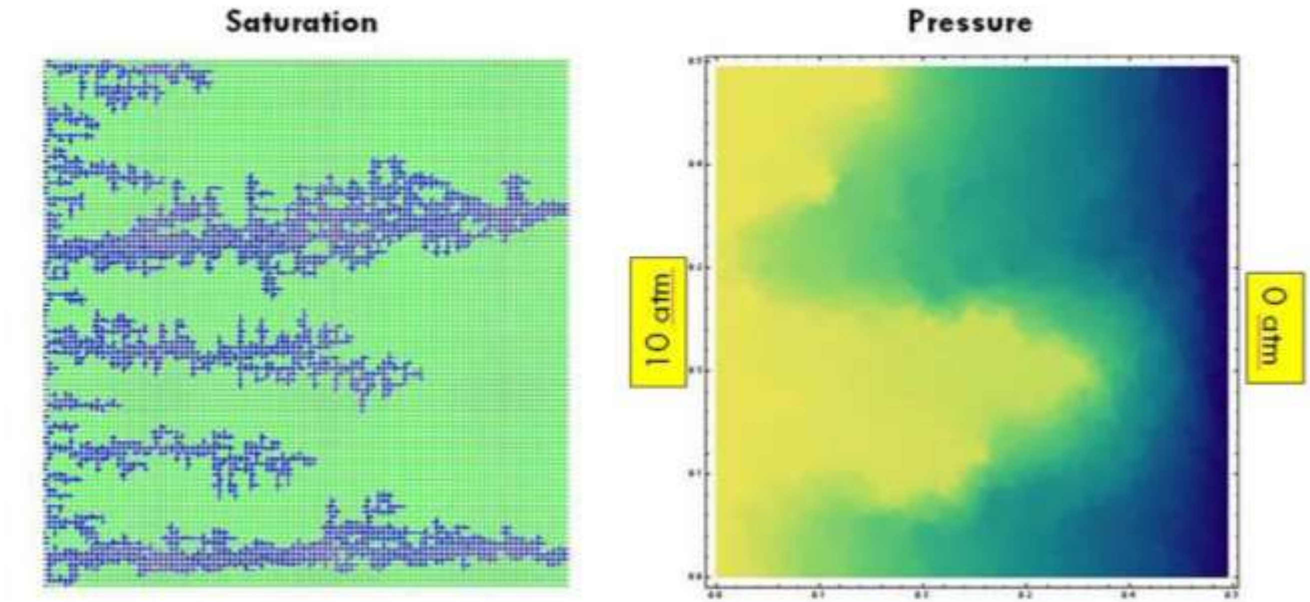




Stable Displacement:
Viscous force (from the invading phase) controls the flood
Pressure drop-Mainly from inlet injection side till front

$$N_C = \frac{q \cdot \mu}{\sum \cdot \sigma} \qquad M = \frac{\mu_{invading}}{\mu_{defending}}$$

Experimental Design



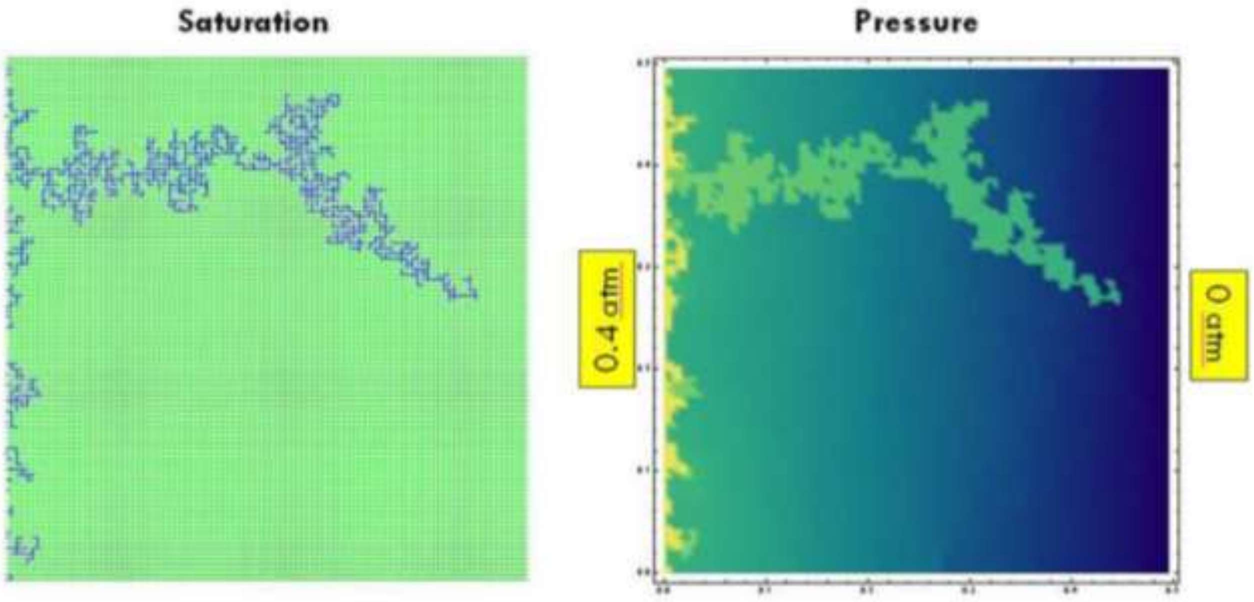
Viscous Fingering:

Viscous force (from the defending phase) controls the flood

Pressure Drop–mainly from finger tip till the outlet end

$$N_C = \frac{q \cdot \mu}{\Sigma \cdot \sigma} \qquad M = \frac{\mu_{invading}}{\mu_{defending}}$$

Experimental Design

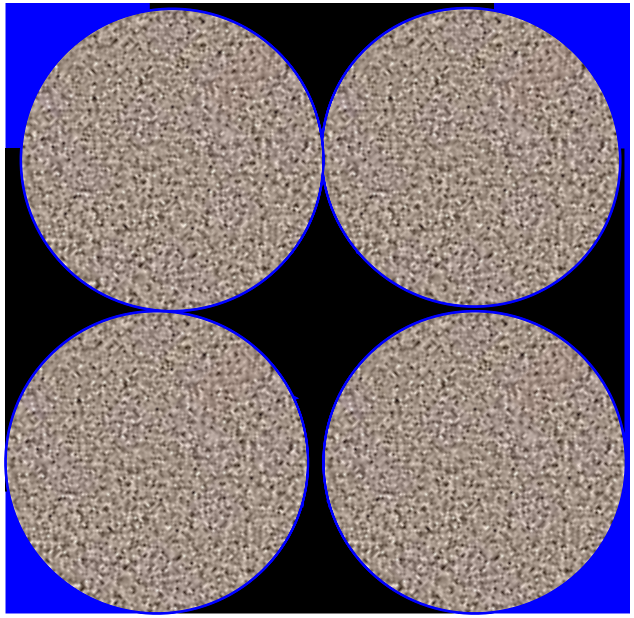


Capillary Fingering:
Capillary forces controls the flood
Pressure drop - In principle constant across the continuous fluid interface

$$N_C = \frac{q \cdot \mu}{\sum \cdot \sigma} \qquad M = \frac{\mu_{invading}}{\mu_{defending}}$$

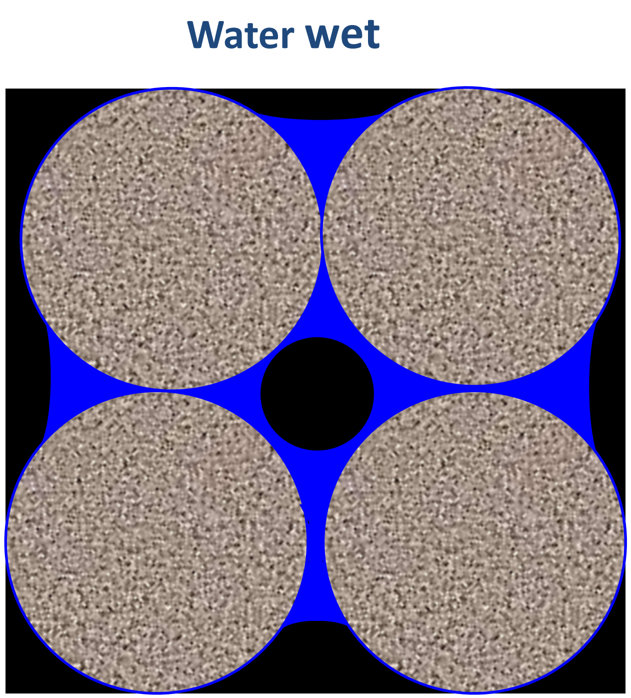
Drainage versus imbibition

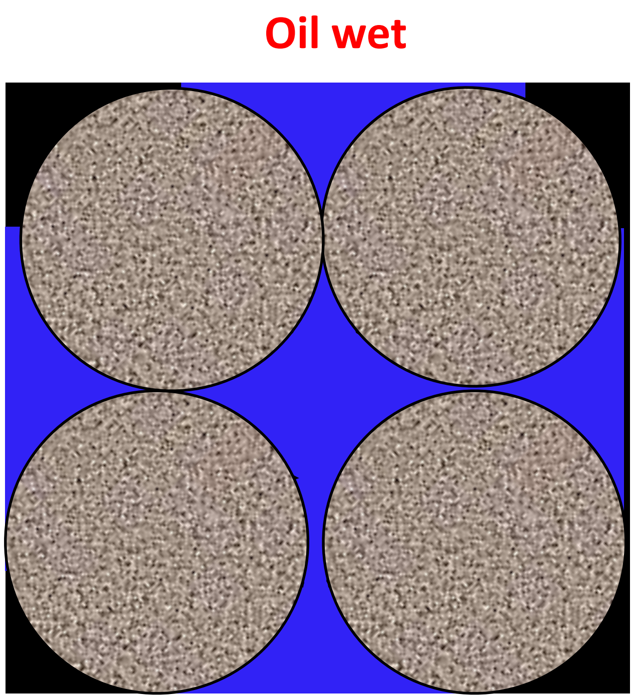
Drainage



•Must be done in initially water wet preference

Drainage versus imbibition

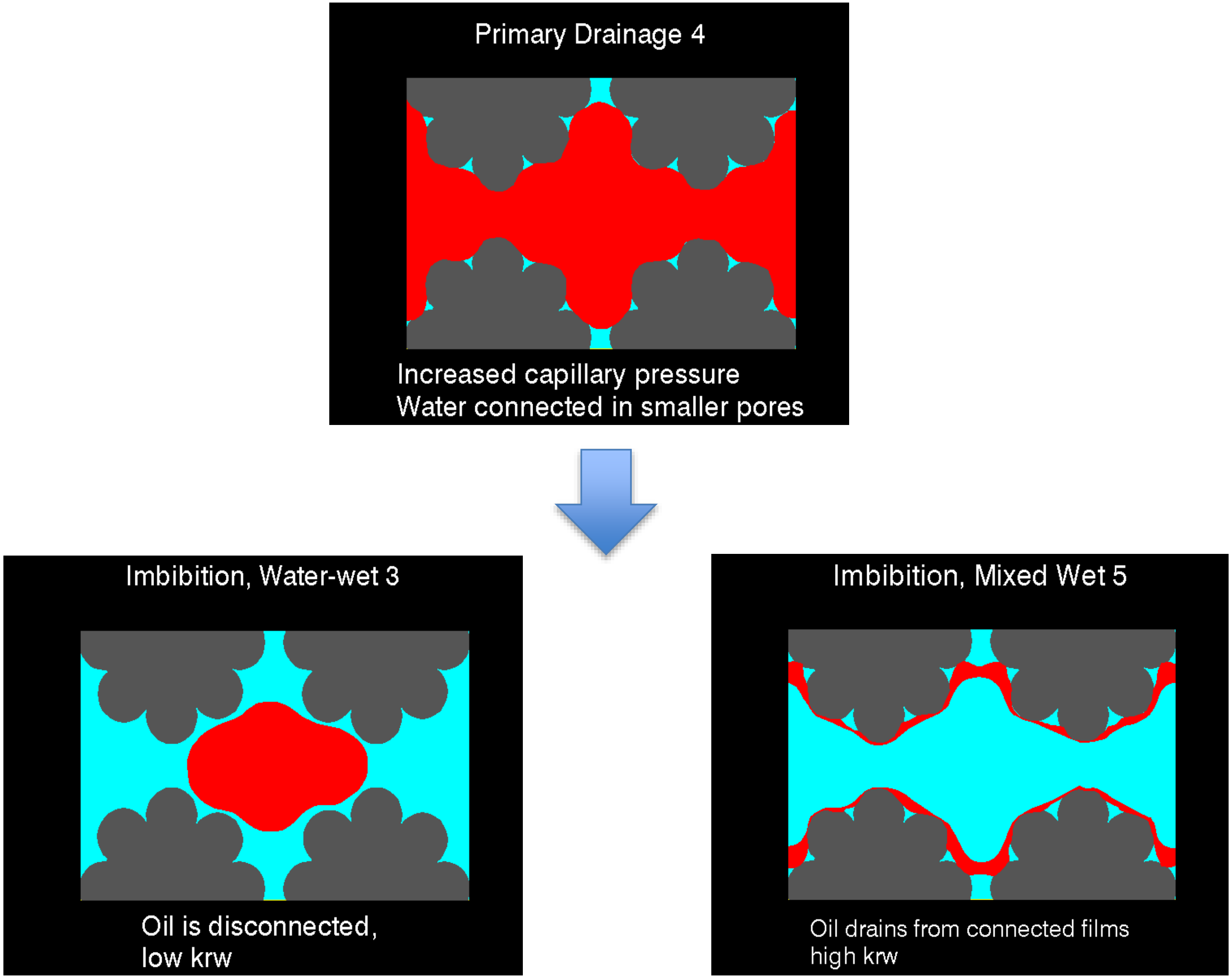




Wettability:

•Affects all multiphase property behavior such as relative permeability, capillary pressure, n-exponent

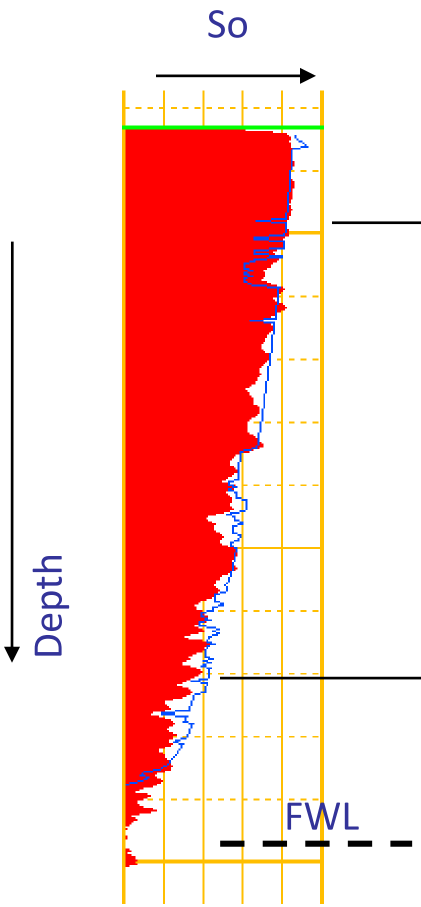
Drainage versus imbibition

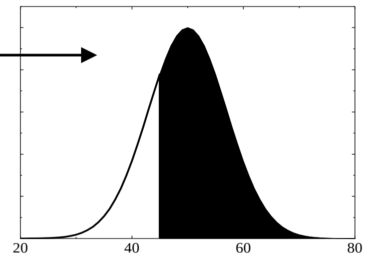


Impact of wettability

Wettability may not be a constant:

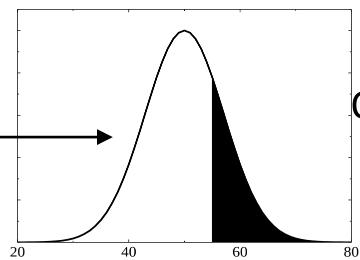
Non invaded capillaries that have never seen oil is water wet (by default)!





Only small pores filled with water

Pore size distribution

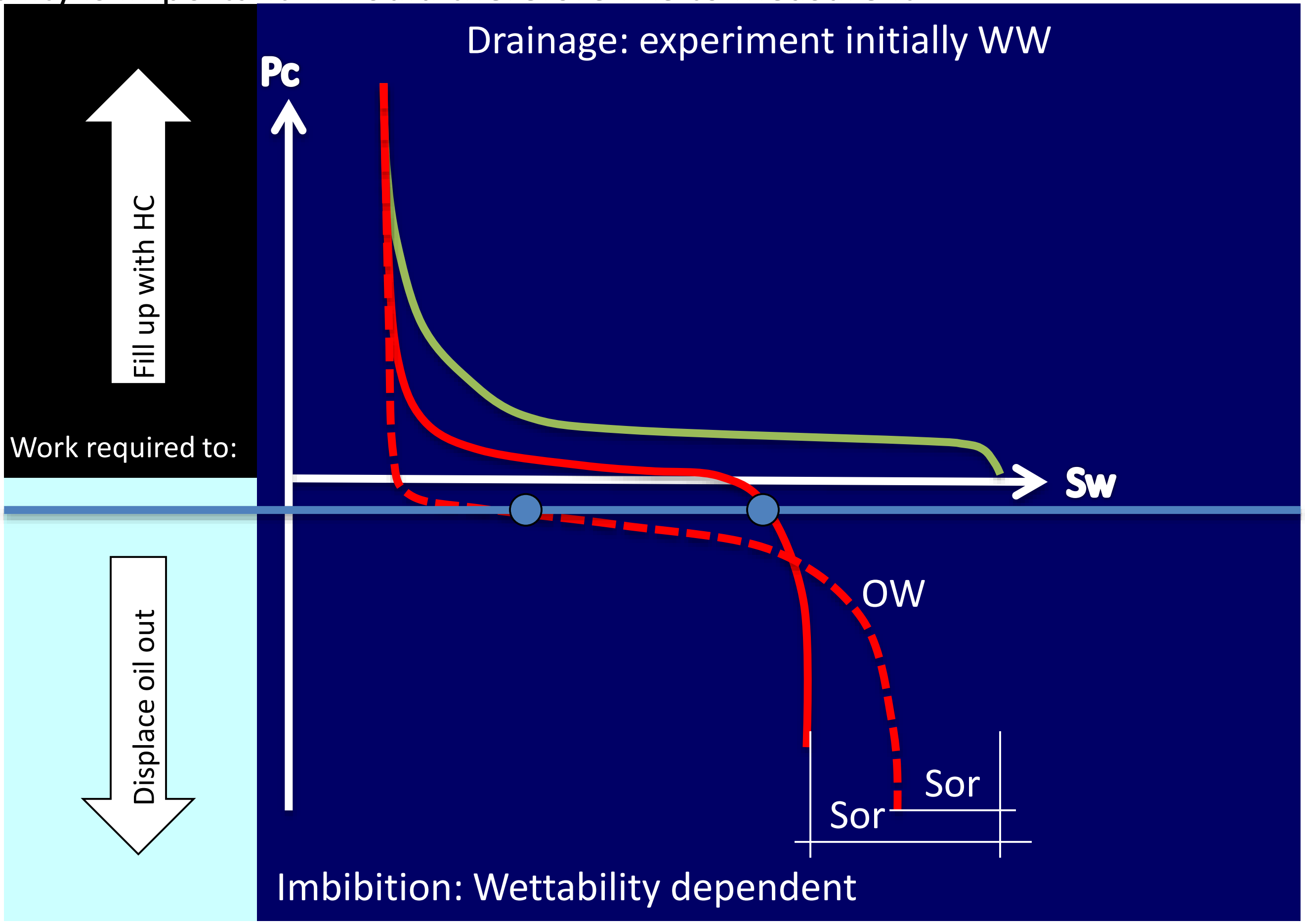


Only large pores are filled with oil

Impact of wettability

Common questions to SCAL experts:

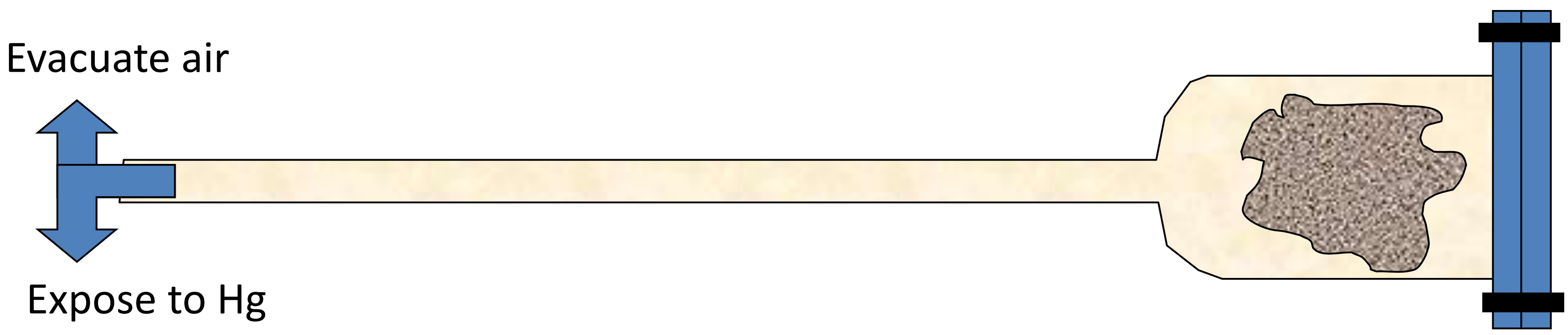
- Field recovery factors is low, so why is Sorw from Pc experiment low ?
- Wettability is important- I would therefore like to measure it



Pc curves are used in dynamic models-while Wettability Index is not

Mercury Injection

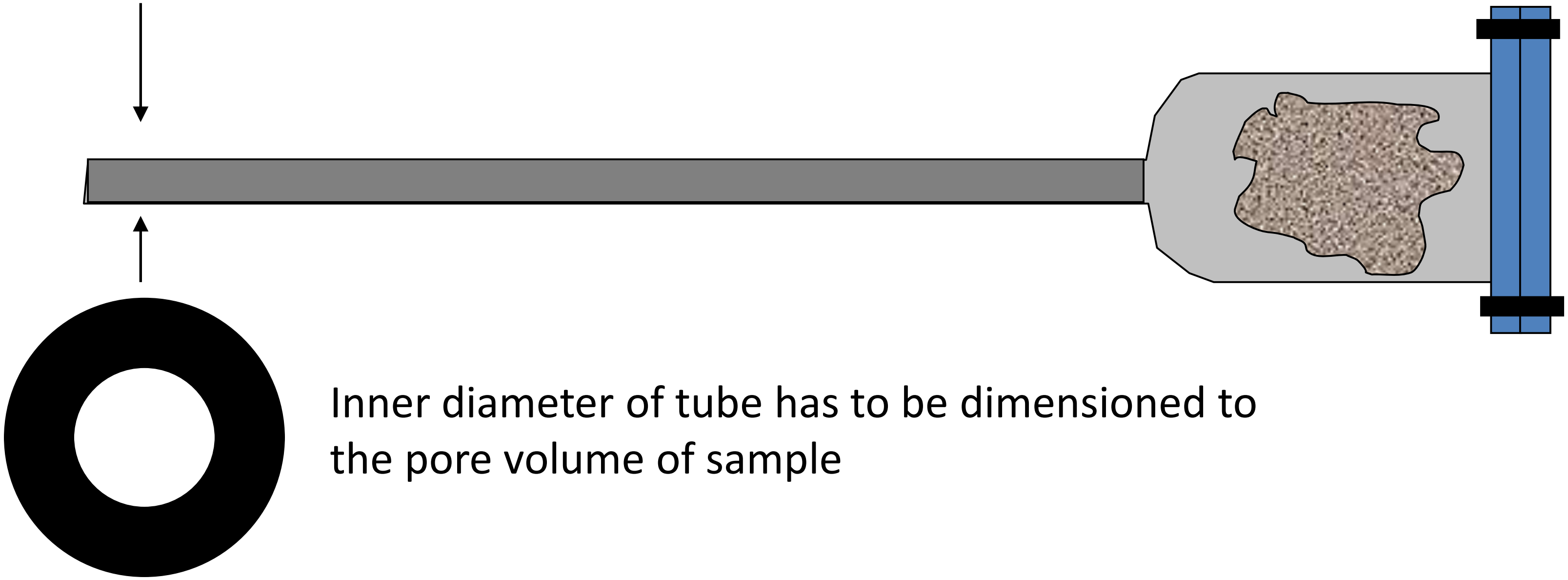
Concept:



Mercury Injection

Concept:

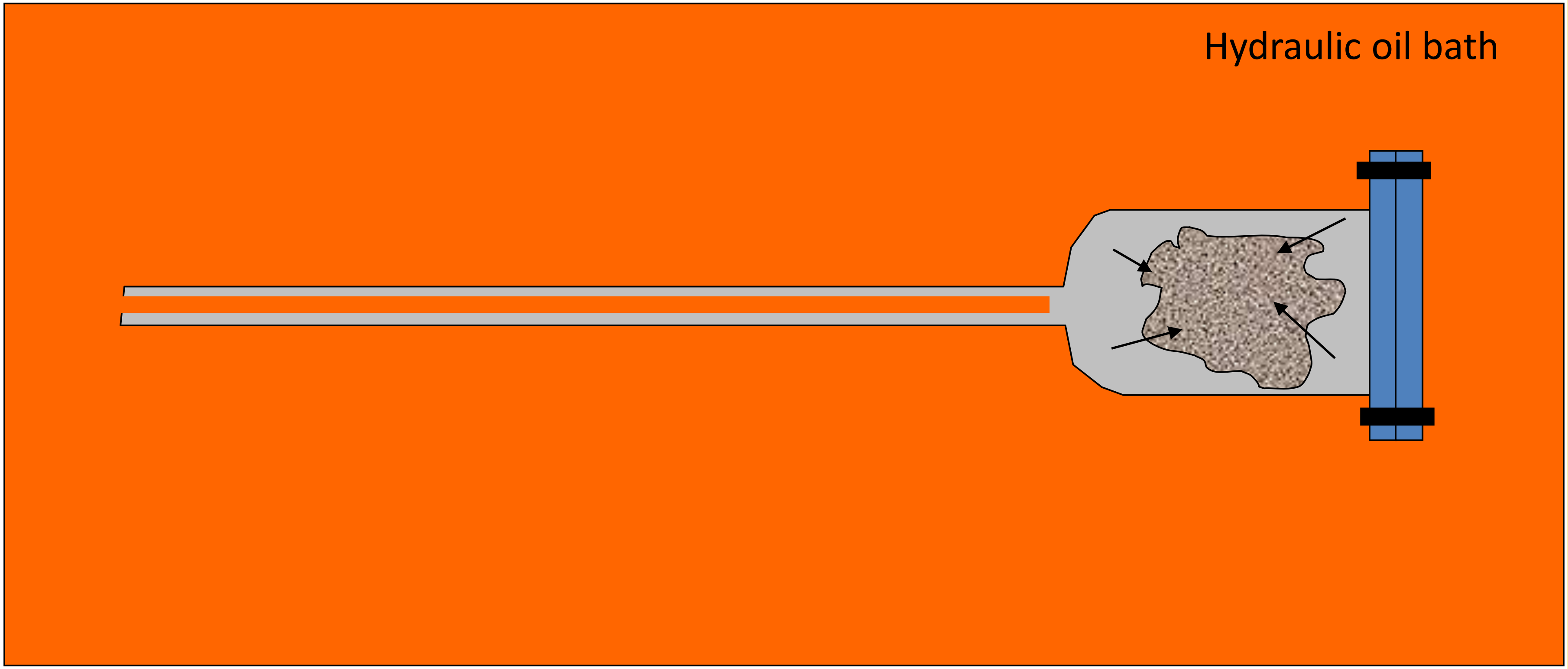
Outer diameter of tube is coated with a conductor



Inner diameter of tube has to be dimensioned to the pore volume of sample

Mercury Injection

Concept:



You are measuring conductance in the tube and pressure in the oil bath

Mercury Injection

Strength:

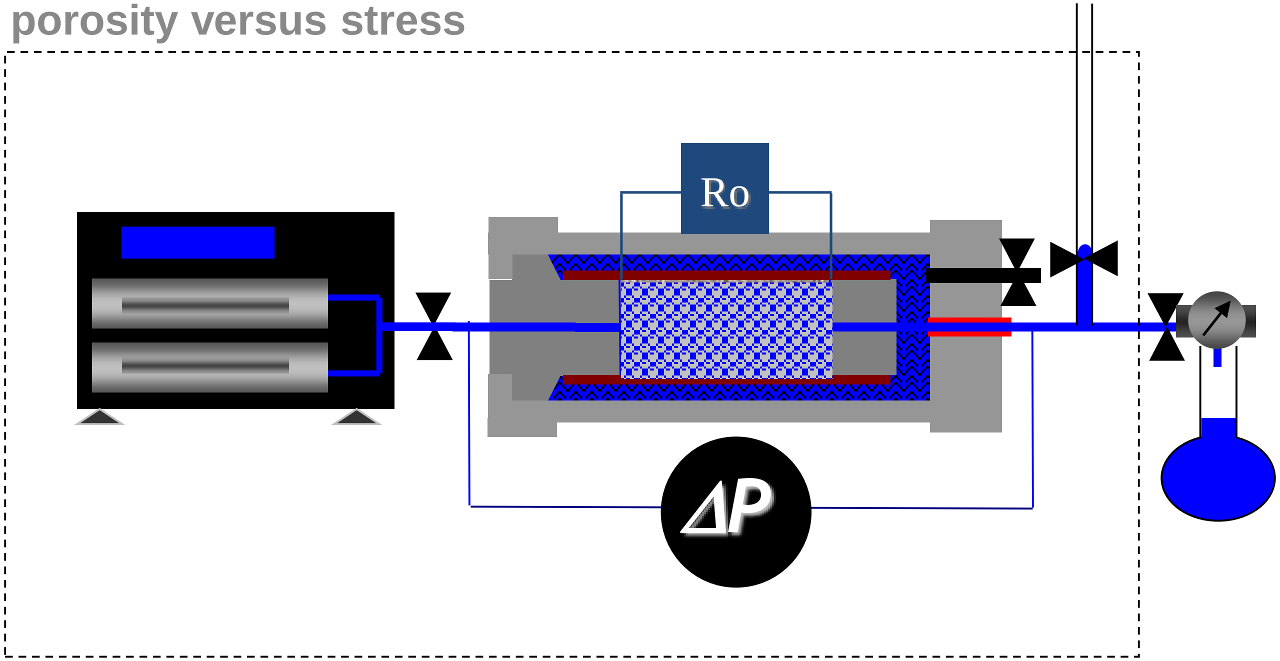
- Very fast technique (around 8 MICP curves per day/ machine)
- Give you simultaneously pore size distribution
- A reliable and accurate technique if proper procedure are established
- Cost

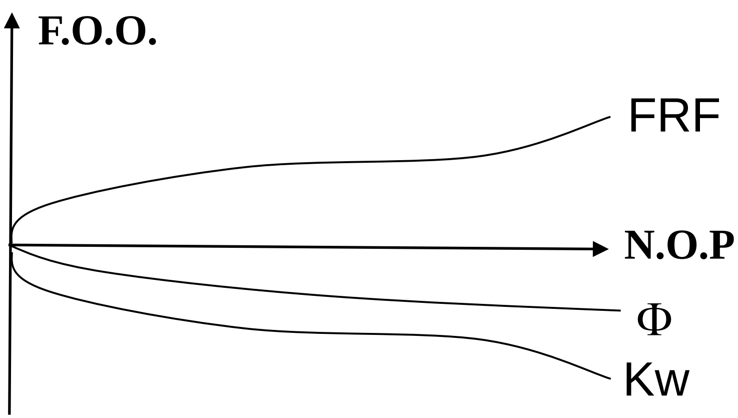
Weakness

- Sample size (limited to a 1 inch core plug with 1 inch length)
- Its NOT a 2-phase experiment (Swc=0 @ 60 000 psi)
- Needs correction (conformance, clay bound water, stress)
- Questionable for vuggy material
- HSE aspect
- Questionable for friable or unconsolidated material
- Can not be combined with electrical properties (n exponent)

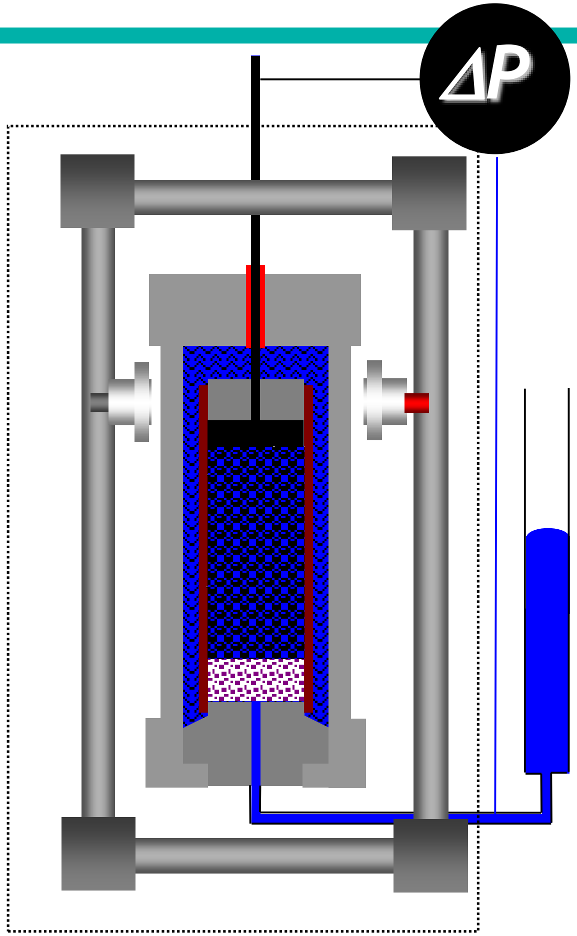
Basic Properties

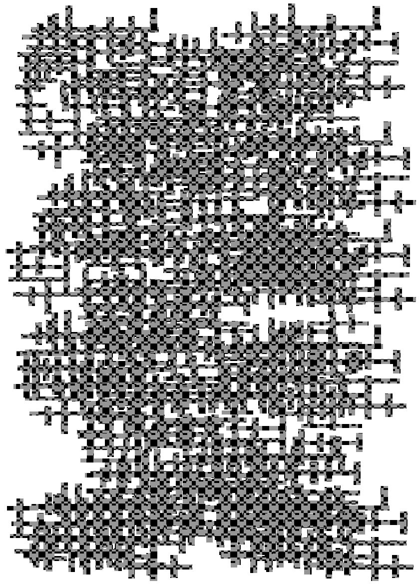
Kw, FRF and porosity versus stress

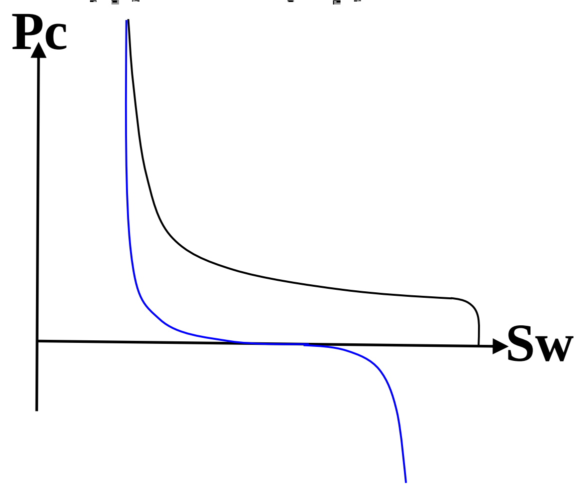


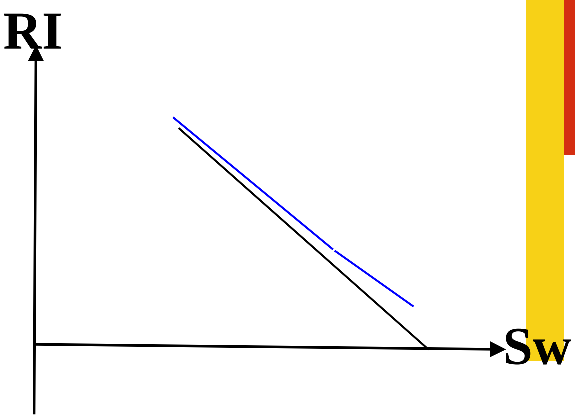


Equilibrium technique (Porous Plate technique)









Equilibrium technique (Porous Plate technique)

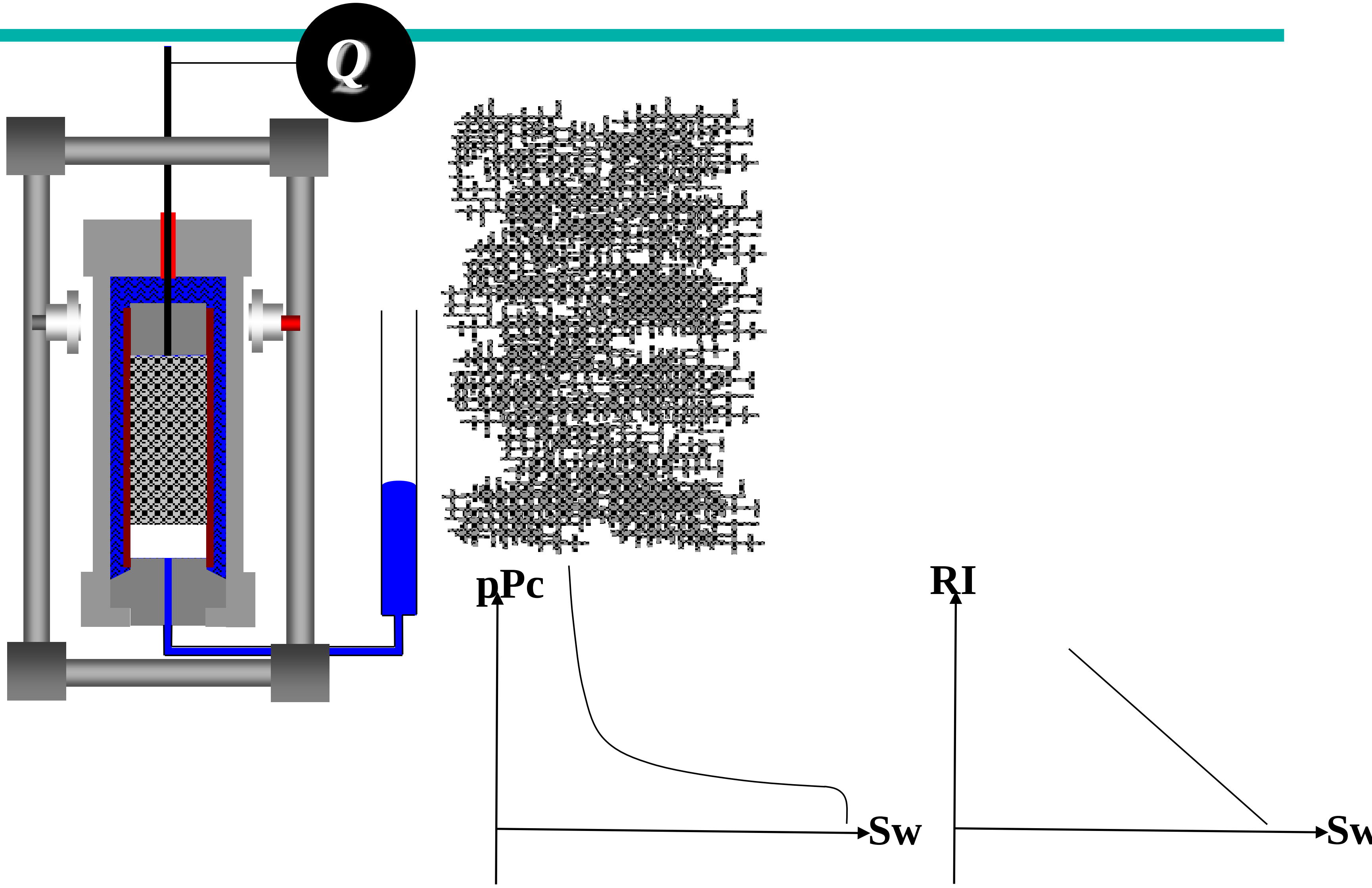
Strength:

- It's a direct technique
- It does not require a model for converting measurements to Sw or Pc
- It yield simultaneously resistivity behavior without changing set-up or conditions.
- It can be used at all types of conditions
- It is slow (from a wettability restoration point of view)

Weakness

- It is slow (from a interpretation point of view)
- In some cases difficult to combine with individual 4 electrode configurations

Continuous Injection method



Continuous Injection method

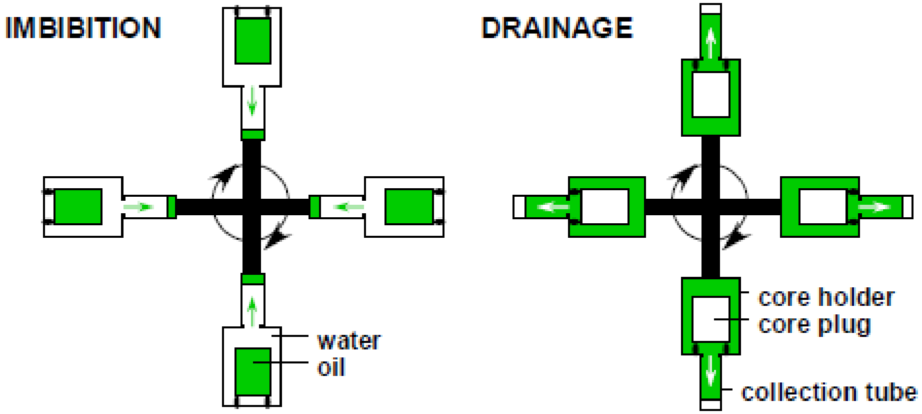
Strength:

- Accurate technique if applied correctly
- It gives fast input parameters for the PP evaluation
- Can be used for all types of conditions
- It does not require a model for Pc and Sw
- Method should always be followed by constant displacement pressure period (constant Pc)

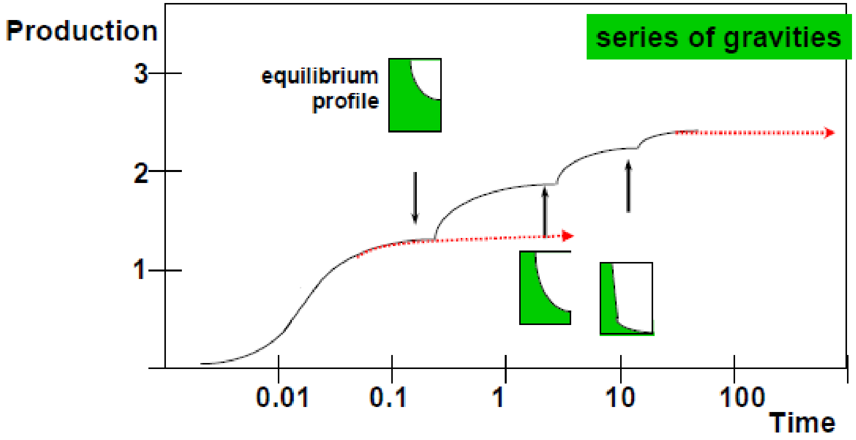
Weakness

- Pseudo Pc is NOT an actual Pc curve
- Require correct rate design (Capillary number and Viscosity Ratio). Can be done by pre-simulations
- The technique have limitations for high viscosity oils and low permeability.
- Design of rates might require pre-simulations

Centrifugation



$$Nb = \frac{\Delta \rho g K}{\sigma}$$



Centrifugation

Calculations:

Average water saturation:

$$Sw(average) = 1 - \frac{V_{produced}}{V_{Pore}}$$

Capillary pressure on the inlet side

$$Pc(inlet) = \Delta\rho \cdot g \cdot L(cm) \cdot 0.01$$

$$g = (2\pi \cdot \omega / 60)^2 \cdot R_m \cdot 0.01$$

Hassler-Brunner: Assumption is constant capillary pressure gradient

$$Pc(HB)_n = \frac{(Pc_{inlet})_n + (Pc_{inlet})_{n-1}}{2}$$

$$Sw(inlet)_n = \frac{\partial Sw_{average} \cdot Pc_{inlet}}{\partial Pc_{inlet}} = \frac{(Sw_{average} \cdot Pc_{inlet})_n - (Sw_{average} \cdot Pc_{inlet})_{n-1}}{(Pc_{inlet})_n - (Pc_{inlet})_{n-1}}$$

Centrifugation

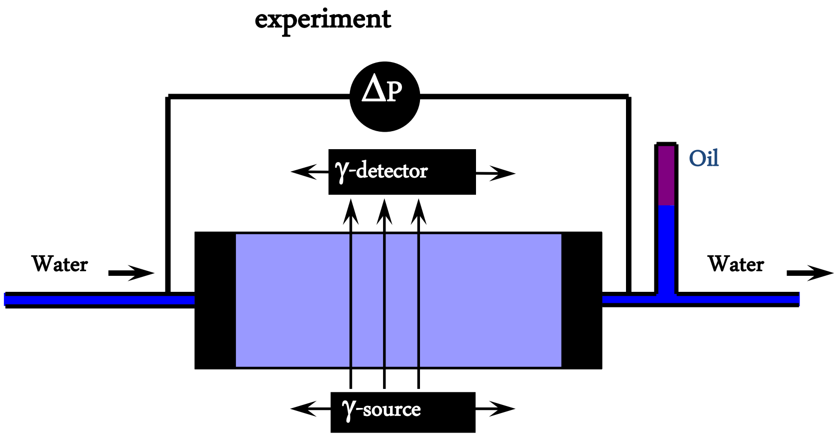
Strength:

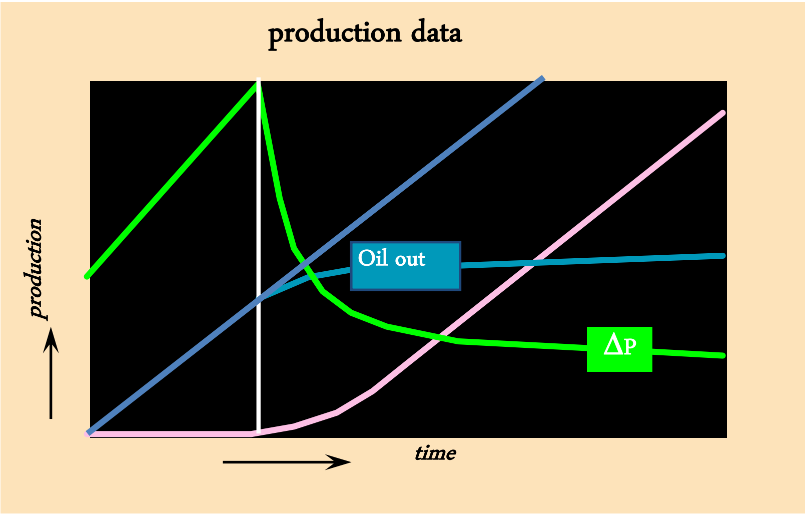
- It is a fast technique
- Can be done with stress.
- Reliable and accurate technique if speed designed is done correctly

Weakness

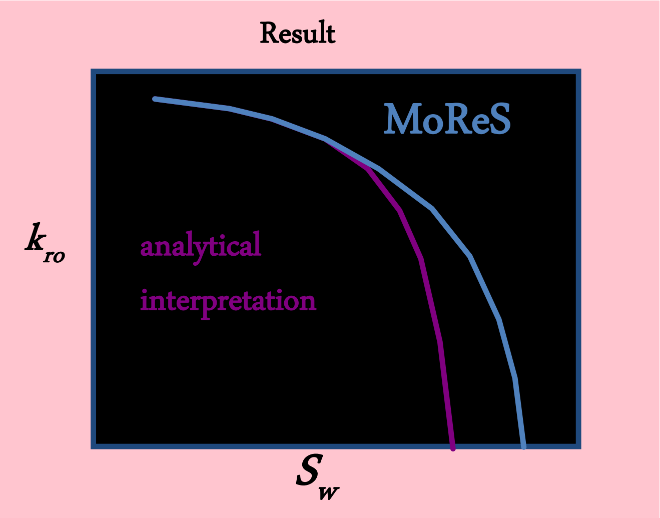
- It requires a model for converting speed to Pc, and volumetric production to Sw (inlet end saturation)
- Pc from lab needs to be corrected before use (by numerical interpretation)
- The technique is questionable for friable and unconsolidated material
- Cannot be combined with electrical properties (n exponent)
- Method have limitations in test temperature

Numerical interpretation of experiments



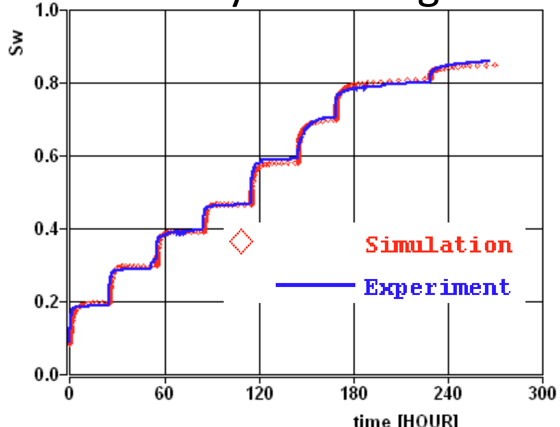


- **MoReS simulations:**
- Capillary pressure
- Mobility both oil & water
- Experimental constraints

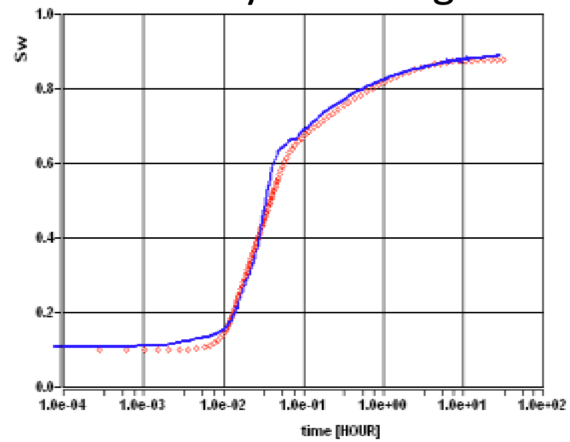


Numerical interpretation of experiments

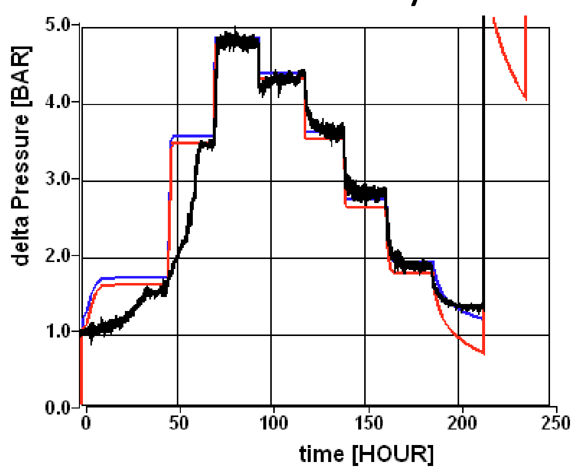
Pc IMB by Centrifugation



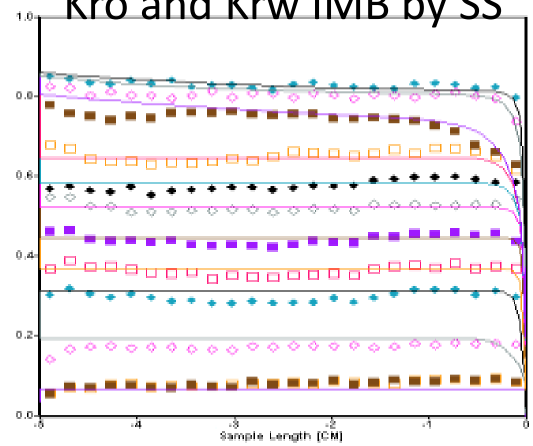
kro IMB by Centrifugation



Kro and Krw IMB by SS



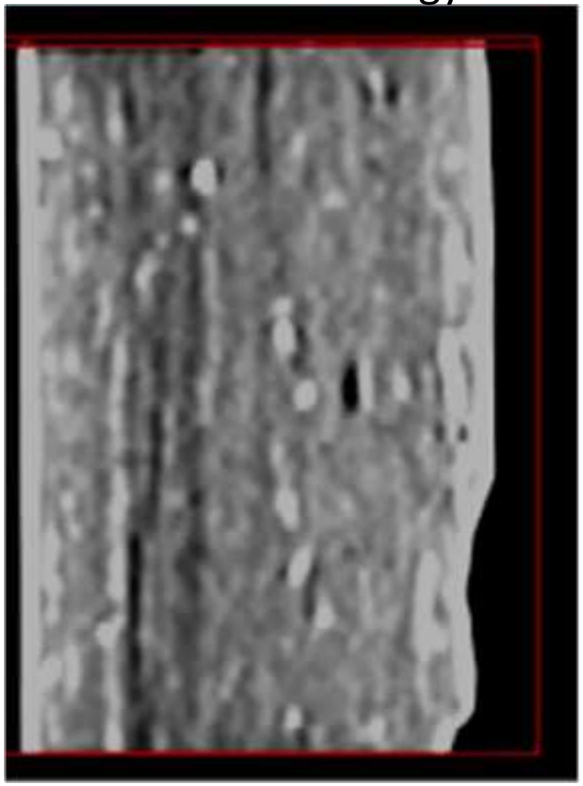
Kro and Krw IMB by SS



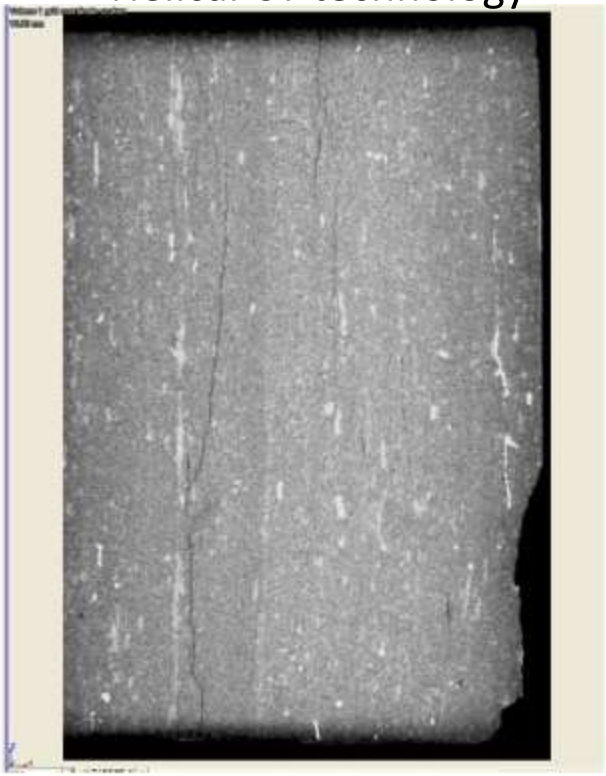
Saturation Profile

Example 1: Misleading lab experiments- plug selection

OLD CT technology

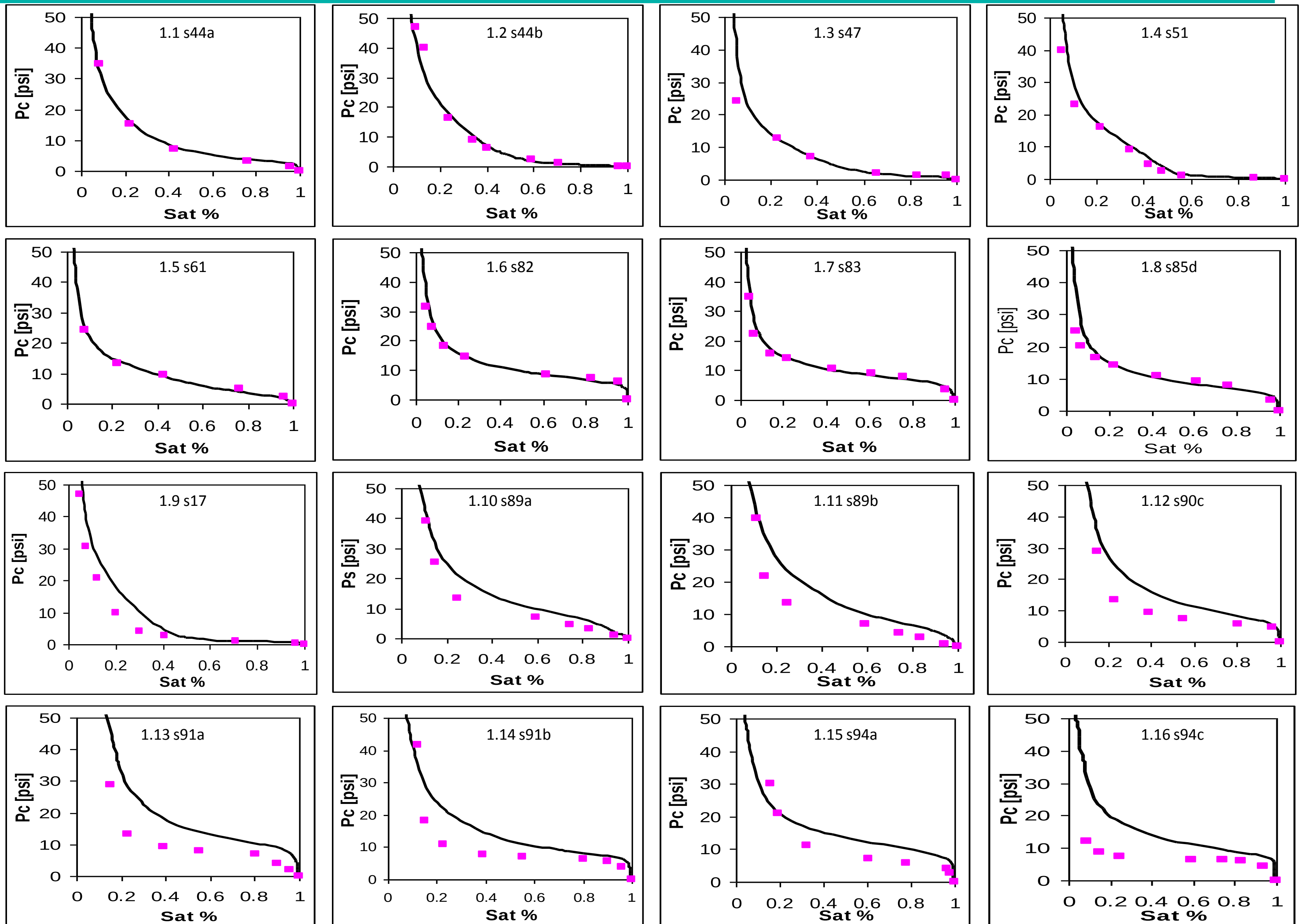


Helical CT technology

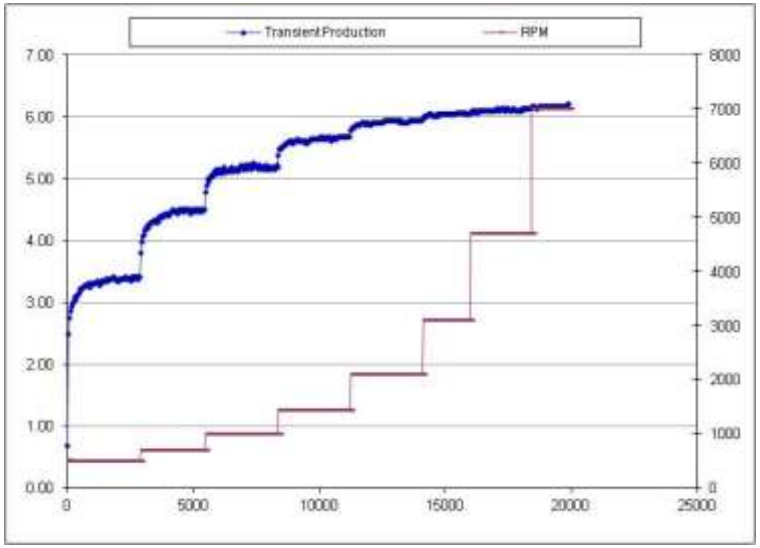


Assessment from LAB: Core Plug is suitable for SCAL

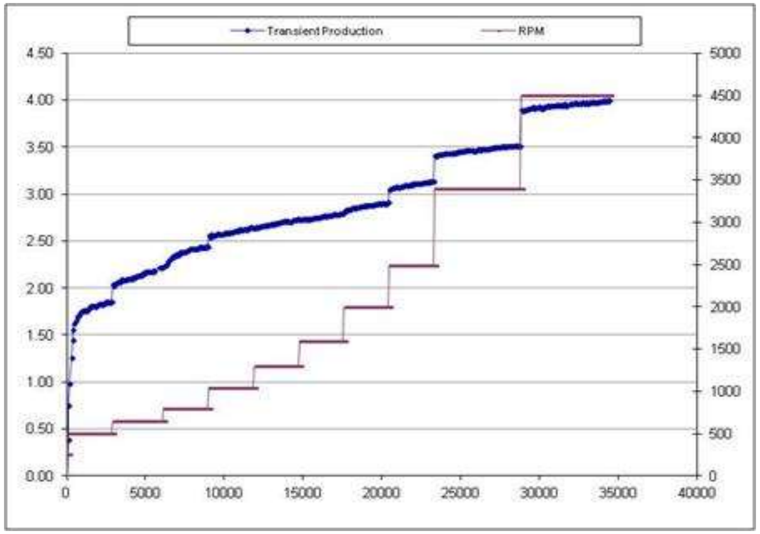
Example 2: Misleading lab experiments – Pc experiments



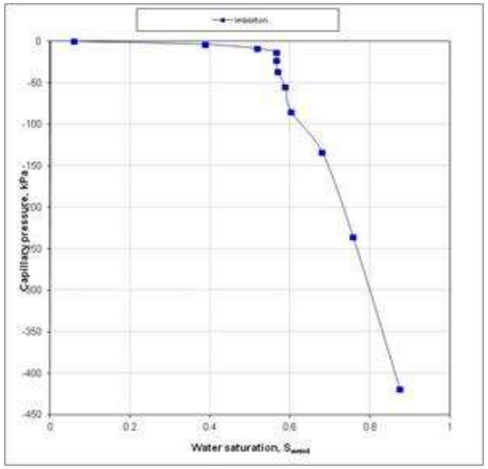
Example 3: Misleading lab experiments -Centrifugation



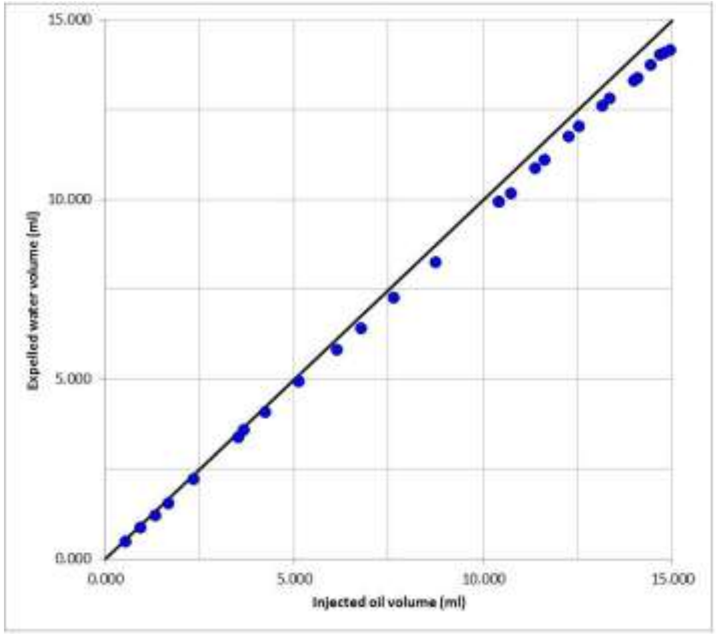
Good quality

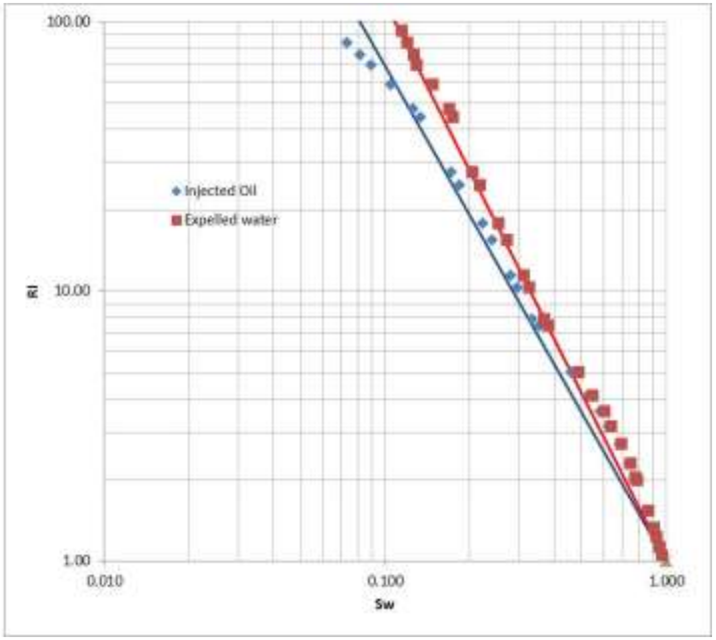


poor quality



Example 4: Misleading lab experiments- CI

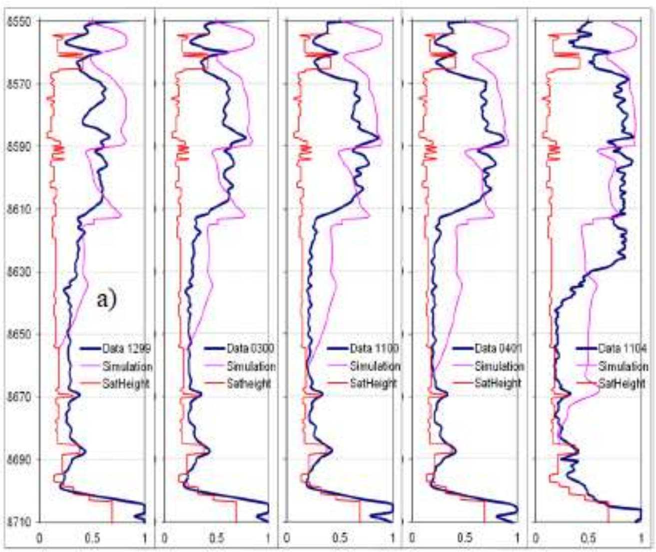




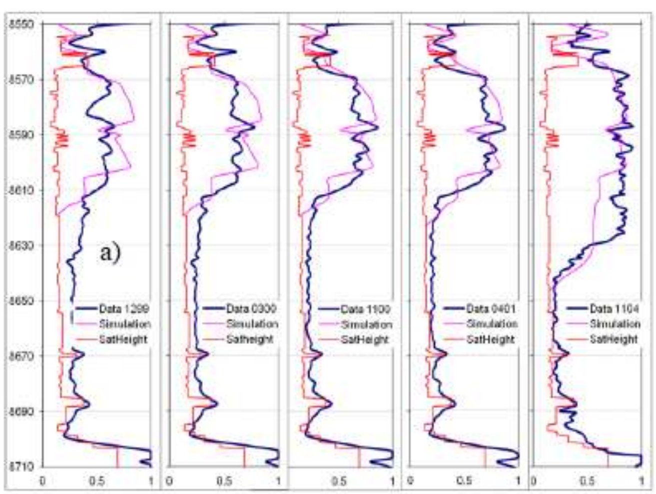
N-exp based on injected oil volume: 1.84 (reported by lab)
N-exp based on expelled water volume: 2.07

Lab's procedure does not take into account oil compressibility

Example 1: Modelling with and without Pc IMB

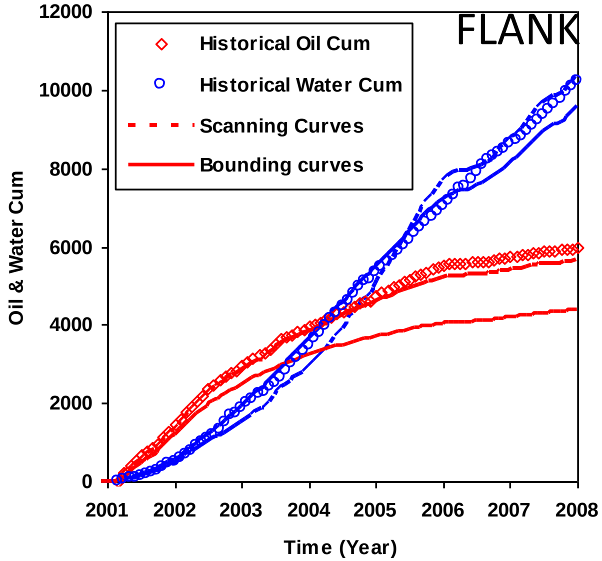


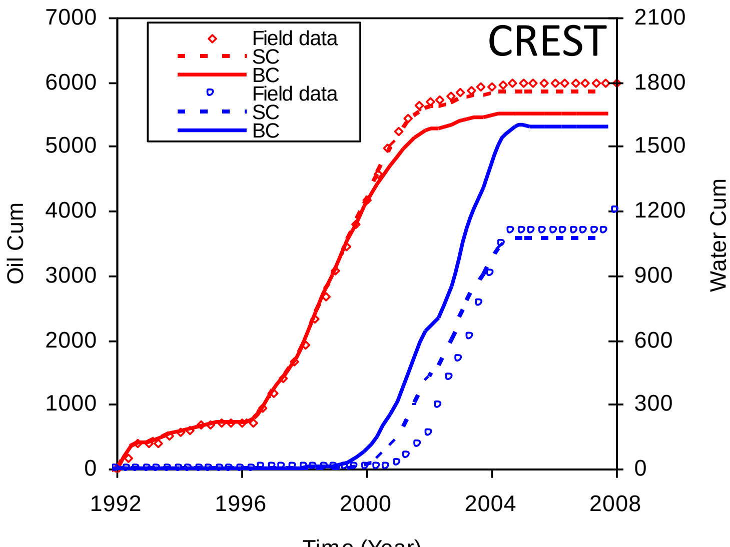
Implemented in dynamic:
Pc(DR)+Kr(IMB)



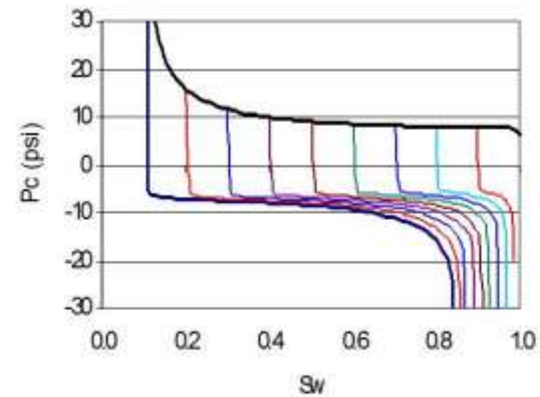
Implemented in dynamic model:
Pc(DR and IMB) + Kr(DR and IMB) with
Scanning curves

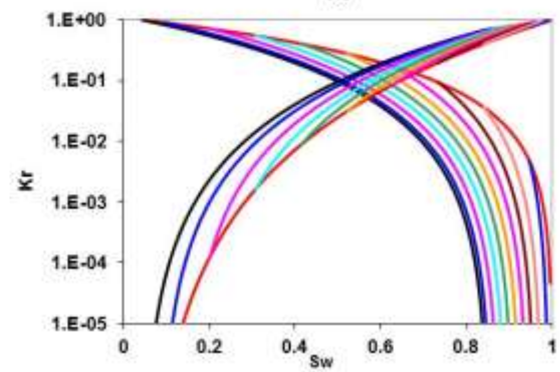
Example 2: Modelled with and without scanning curves





Consistent Pc and Kr
With scanning curves





Example 3: DR versus IMB n-exp in terms of understanding ROS